APPENDIX C
UNDERWATER NOISE MONITORING PLAN

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Project Name

UNDERWATER NOISE MONITORING PLAN

*****TEMPLATE*****

Replace underlined blue italic text with project information.
Blue italic text is guidance.
Plain, black text *is template language.*
All blue italic text should be replaced or omitted for final production.

Prepared by:
Name and full contact information
Signature Block

Date

INTRODUCTION *(This section will be project specific)*

The *full agency name* proposes to *detailed project description*. See vicinity map (Figure 1).

Figure 1. Vicinity map of *name project.*

PROJECT AREA *(This section will be project specific)*

Describe the location of the project, including all water bodies that are affected. Identify the USGS hydrologic unit, both the name and code, where the project is located. Include detailed maps and figures, when available, relative to environmental features that influence monitoring (e.g., geology, bathymetry, etc.).

PERMIT/ESA CONDITIONS *(This section will be project specific and is applicable only when the ESA consultation is complete or Federal/State/local permits have been issued. Each agency should modify this section to reflect the various types of permit/ESA conditions that they see.)*

> *Summarize the Federal/State/local permit conditions and the ESA requirements that relate to the underwater noise. Permit conditions include monitoring requirements, timing restrictions, etc. The ESA requirements are found in the Incidental Take Statement and Terms and Conditions sections of the biological opinion. These requirements vary between biological opinions, but can include monitoring requirements, timing restrictions, limits on cumulative sound exposure level (cSEL) at a given distance, description of the area where the thresholds must not be exceeded, the allowable number of piles driven per day, the allowable number of pile strikes per day, or a limit on the single strike SEL.*

PILE INSTALLATION LOCATION *(This section will be project specific)*

Figure 2 indicates the location of the *provide location of the structure(s) in need of pile driving*. There will be a total of *XX* piles driven as part of the *name structure(s)*.

Figure 2. Location of *name structure(s)* where pile driving activity will take place. *This information must be in enough detail to allow the reader to assess the monitoring locations.*

PILE INSTALLATION

Impact Pile Driving for Fish and Marbled Murrelet Consultations

Provide pile installation information. For example:

Hydroacoustic monitoring will be conducted for *X* piles struck with an impact hammer. Piles chosen to be monitored are driven in water depths that are representative of mid-channel or typical water depths at the project location where piles will be driven.

The number of piles to be monitored will depend on a variety of factors – some projects may require that all piles be monitored, while others may require a representative sample of piles be monitored. If a sample of piles is to be monitored, provide the considerations taken and the rationale used in choosing a representative number of piles, such as, bathymetry, total number of piles to be driven, substrate type, depth of water, distance from shore, river, or stream bank, and *any other considerations, as appropriate. When monitoring a subset, a minimum of 5 piles should be monitored. Additional monitoring to produce a representative sample may be warranted when projects are driving a large number of piles, driving multiple piles of varying diameters in differing substrates, driving different types of piles, or driving piles in widely differing depths.*

Hydroacoustic monitoring of *type of pile* with impact driving will include:

- Monitoring *X piles, out of a total of Y piles driven for the project*.
- Testing sound attenuation system effectiveness.
- *Include airborne noise monitoring as bullet here if necessary for other listed species (e.g., marine mammal haul out present, suitable marbled murrelet nesting habitat present, etc.).*

Figure 3 indicates the location of the piles to be monitored and the approximate hydrophone locations for each pile being monitored. All hydrophones will be placed at least 1 m (3.3 feet) below the surface. *If only one hydrophone at one distance is to be used it is acceptable for the hydrophone to be placed 10 meters from the pile at midwater depth. If hydrophones will be placed at more than one distance from the pile and used to calculate transmission loss over distance, water depth should be at least 4m (13 ft) and it is suggested that the additional hydrophone nearest the pile be placed at least 3H from the pile where H is the water depth at the pile and at 0.7 to 0.85H depth from the surface. In waters less than 4m (13 ft) deep, a single hydrophone at midwater depth is sufficient*[1]. Hydrophones will be located *X* meters from each pile with a clear acoustic line-of-sight between the pile and the hydrophone. *Additional distances measured concurrently are desirable, if possible, to estimate the site specific range to the threshold boundary. Include any additional distances or depths where hydrophones will be located. If airborne noise monitoring is required, the primary measurement microphone shall be placed 50 feet (e.g. 15 meters) from the pile at least 6 feet above the ground or water, and shall have an unobstructed view of the length of the pile.*

[1] Some projects may need or require more than one hydrophone to collect real time measurements at multiple locations or multiple distances. In these situations multiple hydrophones can be placed at midwater depths.

Figure 3. Location of the piles that will be monitored on the *name structure(s)*.

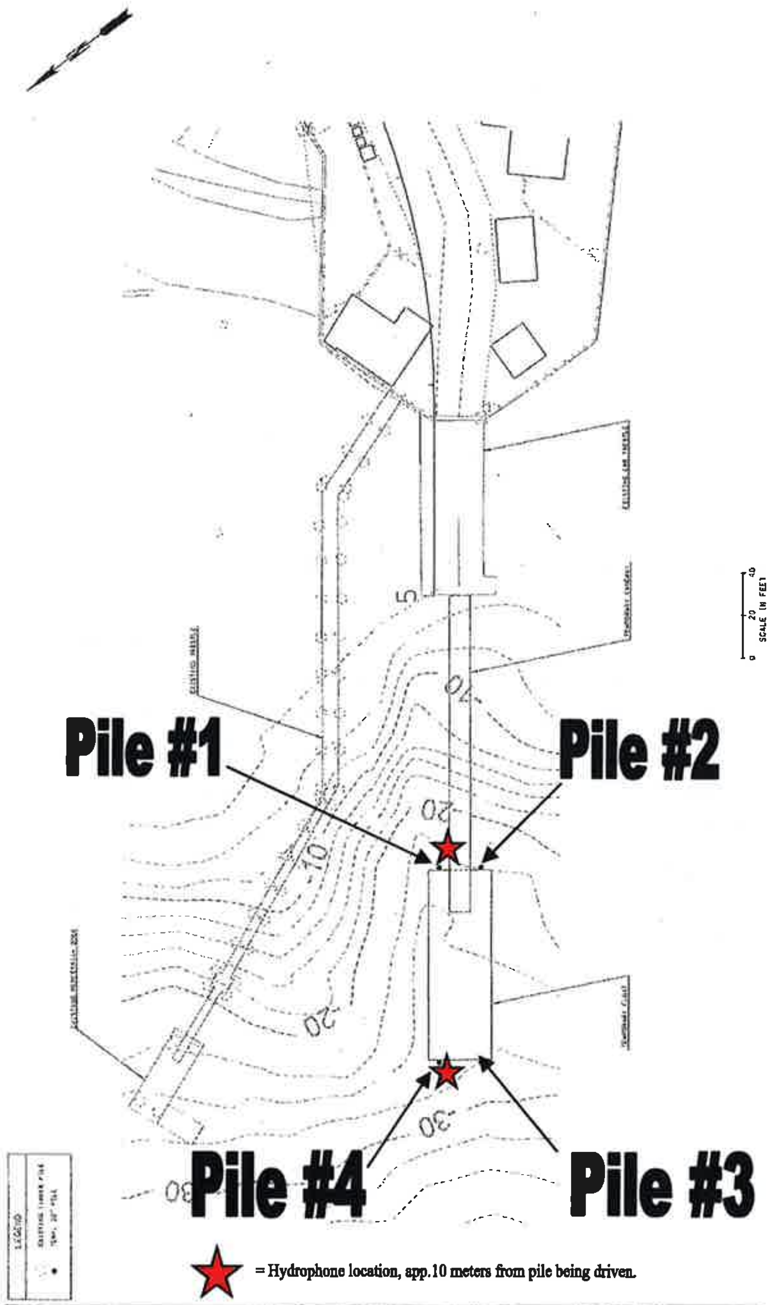

Table 1 lists the *name structure(s)* to be installed, the water depth, and the number and size of piles that will be installed.

Table 1
Depth, Number Piles to be Monitored

Structure	Water Depth	Structural Components Installed
Name structure	X feet to X feet	X - XX-inch diameter type of pile

Vibratory Pile Driving for Marine Mammal Consultations

Currently, hydroacoustic monitoring of vibratory pile installation is not required for fish, marbled murrelet, or marine mammal consultations. Monitoring of vibratory pile installation is voluntary and is designed to evaluate site specific conditions so that the biological monitoring area for marine mammals may be reduced. In addition to the monitoring requirements above, with the exception of a sound attenuation device, NMFS has provided guidance for measuring background and source sound levels as well as how to evaluate site specific propagation loss (NMFS 2012a, b, c). Please use this guidance to develop a plan for hydroacoustic monitoring of vibratory pile installation if applicable.

CONTRACTOR REQUIREMENTS

The contractor will submit a detailed description of their qualifications, which must include a minimum of a bachelor's degree in a related field[2] and 3 years' experience in noise monitoring and analysis, and monitoring plan based on this template for approval by [INSERT AGENCY NAME]. A list of the contractors' proposed sound level monitoring equipment shall be included along with specifications and a description of the purpose. The measurement range in terms of amplitude (in dB referenced to one micropascal (re: 1 uPa)), sensitivity and frequency shall be stated. A minimum frequency range of 20 Hz to 20 kHz and a minimum sampling rate of 48,000 Hz will be used when monitoring. Sampling rates higher than 48 kHz are preferred. Table 2 describes the minimum requirements of the equipment to be used. In addition to the equipment selection, quality control/quality assurance procedures should be described (e.g., how will system responses be verified and how will data be managed).

Table 2.

Equipment for underwater sound monitoring (hydrophone, signal amplifier, and calibrator). All have current National Institute of Standards and Technology (NIST) traceable calibration. *This table is intended as a guideline and exact specifications can be adjusted to meet the needs of the individual project or contractors' equipment.*

Item	Specifications	Minimum Quantity	Usage

[2] This can include Institute of Noise Control Engineering of the USA (INCE/USA) certification or related fields such as acoustics, physics, oceanography, geology or other physical sciences that have required coursework in physics.

Hydrophone	Receiving Sensitivity- -211dB re 1V/μPa	1	Capture underwater sound pressures near the source and convert to voltages that can be recorded/analyzed by other equipment.
Hydrophone	Receiving Sensitivity – -200dB re 1/μPa	1	Capture underwater sound pressures for background levels and convert to voltages that can be recorded/analyzed by other equipment.
Signal Conditioning Amplifier	Amplifier Gain- 0.1 mV/pC to 10 V/pC Transducer Sensitivity Range- 10-12 to 103 C/MU	1	Adjust signals from hydrophone to levels compatible with recording equipment.
Calibrator (pistonphone-type)	Accuracy- IEC 942 (1988) Class 1	1	Calibration check of hydrophone in the field.
Digital Signal Analyzer	Sampling Rate- 48kHz or greater	1	Analyzes and transfers digital data to laptop hard drive.
Microphone (free field type)	Range- 30 – 120 dBA Sensitivity- -29 dB ± 3 dB (0 dB = 1 V/Pa) Wind Screen	1	Monitoring airborne sounds from pile driving activities (if not raining).
If water velocity ~> 1m/s, Flow shield	Open cell foam cover or functional equivalent	1/hydrophone	Eliminate flow noise contamination.
Laptop computer or Digital Audio Recorder	Compatible with digital signal analyzer	1	Record digital data on hard drive or digital tape.
Real Time and Post-analysis software	-	1	Monitor real-time signal and post-analysis of sound signals.

To facilitate further analysis of data full bandwidth, time-series underwater signal shall be recorded as a text file (.txt) or wave file (.wav) or similar format. Recorded data shall not use data compression algorithms or technologies (e.g. MP3, compressed .wav, etc.).

METHODOLOGY

Impact Pile Driving for Fish and Marbled Murrelet Consultations

Underwater background sound level measurements are optional, however, if desired then the NMFS (2012a) guidance should be followed.

If one hydrophone at one distance is to be used it is acceptable for the hydrophone to be placed 10 meters from the pile and at midwater depth. If hydrophones will be placed at more than one distance from the pile it is suggested that the hydrophone nearest the pile be placed at least 3H from the pile where H is the water depth at the pile and 0.7 to 0.85H depth from the surface. The hydrophone*(s)* will be placed at *X meters* depth at a distance of *X meters* from each pile being monitored, in waters of *X meters* depth. *If water velocity is 1 meter/second or greater, 1-3 meters off the bottom may be recommended for near field hydrophones and greater than 5 meters from the surface may be recommended for any far field hydrophones.* A weighted tape measure will be used to determine the depth of the water. The hydrophone*(s)* will be attached to a nylon cord, a steel chain, or other proven anti-strum features if the current is swift enough to cause strumming of the line. The nylon cord or chain will be attached to an anchor that will keep the line the appropriate distance from each pile. The nylon cord or chain will be attached to a float or tied to a static line at the surface. The distances will be measured by a tape measure, where possible, or a range-finder. The acoustic path (line of sight) between the pile and the hydrophone*(s)* should be unobstructed in all cases.

When collecting sound measurements in an area with currents (i.e., in rivers or tidally influenced areas), appropriate measures will be taken, when necessary, to ensure that the flow-induced noise at the hydrophone will not interfere with the recording and analysis of the relevant sounds (NMFS, 2012a). As a general rule, current speeds of 1.5 meters/second or greater are expected to generate significant flow-induced noise, which may interfere with the detection and analysis of low-level sounds such as the sounds from a distant pile driver or background sounds. If such measures are necessary, include a description of those measures. For example:

> *If it becomes necessary to reduce the flow-induced noise at the hydrophone, a flow shield will be described and installed around the hydrophone to provide a barrier between the irregular, turbulent flow and the hydrophone. If no flow shield is used in these situations, the current velocity will be measured and a correlation between the levels of the relevant sounds (background or pile driving) and current speed will be made to determine whether the data is valid and can be included in the analysis.*

The hydrophone calibration*(s)* will be checked at the beginning of each day of monitoring activity. *The method of calibration and calibration equipment used will be described.* NIST traceable calibration forms shall be provided for all relevant monitoring equipment. Prior to the initiation of pile driving, the hydrophone will be placed at the appropriate distance and depth as described above.

The onsite inspector/contractor will inform the acoustics specialist when pile driving is about to start to ensure that the monitoring equipment is operational. Underwater sound levels will be continuously monitored during the entire duration of each pile being driven with a minimum one-third octave band frequency resolution. The wideband instantaneous absolute peak pressure and Sound Exposure Level (SEL) values of each strike, and daily cumulative SEL should be monitored in real time during construction to ensure that the project does not exceed its authorized take level. Peak and rms pressures will be reported in dB (re:1 μPa). SEL will be reported in dB (re: 1 $\mu Pa^2 \cdot sec$). Wideband time series recording is strongly recommended during all impact pile driving.

Prior to, and during, the pile driving activity, environmental data will be gathered, such as water depth and tidal level, wave height, and other factors that could contribute to influencing the underwater sound levels (e.g. aircraft, boats, etc.). Start and stop time of each pile driving event and the time at which the bubble curtain or functional equivalent[3] is turned on and off will be logged.

The contractor or agency will provide the following information, in writing, to the contractor conducting the hydroacoustic monitoring for inclusion in the final monitoring report: a description of the substrate composition, approximate depth of significant substrate layers, hammer model and size, pile cap or cushion type, hammer energy settingsand any changes to those settings during the piles being monitored, depth pile driven, blows per foot for the piles monitored, and total number of strikes to drive each pile that is monitored.

If airborne noise monitoring is required, background measurements from 20 Hz to 20 kHz will be taken to establish background noise without the pile driver and associated equipment running. Spectral analysis shall be provided showing the frequency content of the background noise spectra using a minimum bandwidth resolution of one-third octave using both A-weighted and unweighted filters. For monitoring pile driving noise, the microphone shall be positioned 50 feet from the driven pile, at least 6 feet above the ground, water, or deck level. The microphone should not be positioned near other noisy equipment, such as the crane engine, compressors, while operating. Equipment used for airborne noise measurements shall demonstrate calibration traceability to NIST standards.

Vibratory Pile Driving for Marine Mammal Consultations

If hydroacoustic monitoring of vibratory pile installation is conducted for marine mammal consultations NMFS (2012a,b,c) guidance should be followed. In addition to the monitoring methodology above, the following differences should be noted:

- *Use of a sound attenuation device is not required*
- *Placement of the hydrophones*

NMFS has provided guidance for measuring background and source sound levels as well as how to evaluate site specific propagation loss (NMFS 2012a, b, c). Please use this guidance to develop a methodology for hydroacoustic monitoring of vibratory pile installation if applicable.

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[3] A functional equivalent must function as well as or better than the attenuation device that was proposed during consultation or required by the ESA consultation or applicable permits. It must achieve the same or better sound level reductions that were used in the calculations during ESA consultation or the permitting process.

If marine mammals are present in the project area it is recommended that background sound levels be measured to more accurately determine the site specific range to the threshold using the protocol outlined in NMFS 2012a. Background underwater sound levels will be measured for a minimum of three full 24-hour cycles (i.e., 6 am to 6 am) in the absence of construction activities to determine background sound levels (NMFS, 2012a). Analysis will be conducted using both data from the full range of frequencies recorded (typically 20 Hz to 20 kHz) and using high pass filters at 7 Hz, 75 Hz, and 150 Hz thus eliminating those frequencies below these levels (NMFS, 2012a) which follows the marine mammal functional hearing groups of Southall et al. (2007). Data will be used to calculate 30-second Root Mean Square (RMS) values for each 30 seconds of the three 24-hour cycles measured. These data will be used to calculate and plot a Cumulative Distribution Function (CDF) (NMFS, 2012a). Overall background sound levels will be reported as the 50% CDF and include a spectral analysis of the frequencies (NMFS, 2012a) for a minimum of one hourly cycle. *Alternately, if pile driving will be conducted during the daytime only the background sound levels collected during daytime hours (6am to 6pm) can be used in this analysis.*

If only one hydrophone at one distance is to be used it is acceptable for the hydrophone to be placed 10 meters from the pile at midwater depth. If hydrophones will be placed at more than one distance from the pile it is suggested that the hydrophone nearest the pile be placed at least 3H from the pile where H is the water depth at the pile and at 0.7 to 0.85H depth.

If water velocity is 1 meter/second or greater, 1-3 meters off the bottom may be recommended for near field hydrophones and greater than 5 meters from the surface may be recommended for any far field hydrophones.

Include information on methodology, instrument specifications and settings and measurement location if airborne measurements are to be included for other listed species (e.g., marine mammal haul out present, marbled murrelet nesting habitat present, etc.), as required.

Sound Attenuation Monitoring

All monitored piles may be tested with the sound attenuation system on and off (or presence and absence) to test its effectiveness[4]. To account for varying resistance as the pile is driven; the sound attenuation device will be turned off for *(describe schedule for turning on and off)* periods during the beginning, the middle third, and near the end of the drive. After turning off the attenuation system, pile driving should not resume for at least 2 minutes to allow time for air bubbles to completely disperse. *For piles that require less than 5 minutes to drive, pile driving should occur for only two periods with the bubbles off, one near the beginning and once near the end of the drive.*

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[4] Note: There may be circumstances where the U.S. Fish and Wildlife Service determines that unattenuated pile driving (striking the pile with the bubble curtain turned off) would pose a significant risk of injury to marbled murrelets. In those situations, the Service may request that unattenuated pile driving does not occur and that hydroacoustic monitoring be conducted to determine the extent at which certain thresholds are met instead. This will need to be determined on a case by case basis for projects that may affect marbled murrelets.

SIGNAL PROCESSING

Impact Pile Driving for Fish and Marbled Murrelet Consultations

Post-analysis of the underwater pile driving sounds will include:

- Number of pile strikes per pile and per day.
- For each recorded strike (or each strike from a subset), determine the following:
    - The peak pressure, defined as the maximum absolute value of the instantaneous pressure (overpressure or underpressure).
    - The root mean squared sound pressure across 90% of the strikes energy ($RMS_{90\%}$).
    - Sound exposure level, measured across 90% of the accumulated sound energy ($SEL_{90\%}$). Calculation methodology is provided in Appendix A.
- Maximum, mean, and range of the peak pressure, with, and if applicable, without attenuation.
- Maximum, mean, range, and Cumulative Distribution Function (CDF) of the $RMS_{90\%}$, both with and if applicable, without attenuation where the CDF is used to report the percentage of $RMS_{90\%}$ values above the thresholds.
- Maximum, mean, and range of the $SEL_{90\%}$, both with and if applicable, without attenuation.
- Cumulative SEL (cSEL) across all of the pile strikes. If SEL was calculated for all strikes, cSEL is estimated as indicated in Appendix A. If SEL was calculated for a subset of strikes, cSEL is estimated as follows: cSEL = SEL_{mean} + 10*log(total # strikes).
- Where surrogate piles are monitored to represent a larger project, an estimate of the cSEL during a typical day of construction driving must be reported by summing the SEL over the expected number of pile strikes in a typical day for the larger project: cSEL = SEL_{mean} + 10*log(#strikes). The SEL_{mean} used in this calculation must correspond with the actual sound attenuation measures that will be used during construction of the larger project.
- A frequency spectrum both with and, *if applicable*, without attenuation, between a minimum of 20 and 20 kHz for up to eight successive strikes with similar sound levels.

If airborne noise monitoring is required, both A-weighted and unweighted measurements will be acquired. Broadband back-to-back RMS L_{max} (peak) and L_{eq} (average) 5-minute measurements will be made over the duration of pile driving,. L_{max} measurements should be taken with a portable analyzer set for "fast" response (125 msec). For at least one full pile sequence of each pile size and substrate type, frequency spectrum measurements (L_{max} and L_{eq}) using a minimum resolution of one-third octave bands shall be taken to show the spectral content of the impact pile. If measuring background sound levels in the absence of construction is not possible, then report the L_{95} statistic.

Vibratory Pile Driving for Marine Mammal Consultations

Background sound levels will be analyzed by calculating 30-second RMS values and plotting these values on a CDF. The average background sound level will be estimated using the 50% CDF (See Appendix B).

If vibratory installation of piles will be monitored for marine mammals, add the following text: Vibratory monitoring data will be analyzed by calculating 10-second RMS values for every 10 seconds for each pile. The 10-second RMS values will be averaged for the entire pile and reported as the average RMS. The average RMS will be calculated for each marine mammal functional hearing group as reported by Southall et al. (2007) (NMFS, 2012b).

ANALYSIS

Impact Pile Driving for Fish and Murrelet Consultations

Analysis of the data from the San Francisco-Oakland Bay Bridge Pile Installation Demonstration project (PIDP) indicated that 90 percent of the acoustic energy for most pile driving impulses occurred over a 50 to 100 millisecond period with most of the energy concentrated in the first 30 to 50 milliseconds (Illingworth and Rodkin, 2001). The RMS values computed for this project will be computed over the duration between where 5% and 95% of the energy of the pulse occurs. The SEL energy plot will assist in interpretation of the single strike waveform. The single strike SEL associated with the highest absolute peak strike along with the total number of strikes per pile and per day will be used to calculate the cumulative SEL for each pile and each 24-hour period.

In addition a waveform analysis of the individual absolute peak pile strikes will be performed to determine any changes to the waveform with the *name type of noise attenuation device*. A comparison of the frequency content with and without noise attenuation will be conducted. Units of underwater sound pressure levels will be dB (re:1 µPa)and units of SEL will be re:1 $\mu Pa^{2}\bullet$sec.

Vibratory Pile Driving for Marine Mammal Consultations

If vibratory installation will be monitored for marine mammals, add the following text: Vibratory monitoring results will include the maximum and average RMS values for each pile monitored and a comparison of the frequency content between piles. The maximum and overall average RMS calculated from 10-second RMS values during the drive of the pile for will be calculated for each of the functional hearing groups of Southall et al. (2007) (NMFS, 2012b).

REPORTING

If sound attenuation devices are used during the monitoring, include the following text and analysis:

An analysis of the change in the waveform and sound levels with and without the *name type of noise attenuation device for impact driving* operating will be conducted.

Preliminary results for the daily monitoring activities, if required, will be submitted/reported to the primary point of contact[5] at each of the Services within *X hours* after monitoring concludes

[5] The primary point of contact is the biologist that conducted the Section 7 consultation for the Service(s). In the event that the consulting biologist is not available, communication regarding monitoring results and reports should be addressed to the manager of the consultation branch or division with a reference to the consultation title.

for the day. In addition a final draft report including data collected and summarized from all monitoring locations will be submitted to the Services within 90 days of the completion of hydroacoustic monitoring. The results will be summarized in graphical form and include summary statistics and time histories of impact sound values for each pile. A final report will be prepared and submitted to the Services within 30 days following receipt of comments on the draft report from the Services. The report shall include:

1. Size and type of piles.
2. A detailed description of the *name type of noise attenuation device*, including design specifications *(if applicable)*.
3. The impact hammer energy rating used to drive the piles, make and model of the hammer.
4. A description of the sound monitoring equipment.
5. The distance between hydrophone*(s) or microphone(s)* and pile.
6. The depth of the hydrophone*(s)* and depth of water at hydrophone locations.
7. The distance from the pile to the water's edge.
8. The depth of water in which the pile was driven.
9. The depth into the substrate that the pile was driven.
10. The physical characteristics of the bottom substrate into which the piles were driven.
11. The total number of strikes to drive each pile and for all piles driven during a 24-hour period.
12. The underwater wideband background sound pressure level reported as the 50% CDF *(if applicable)*.
13. The results of the hydroacoustic monitoring, as described under Signal Processing. An example table is provided in Appendix C for reporting the results of the monitoring.
14. The distance at which peak, cSEL, and rms values exceed the respective threshold values.
15. *If vibratory installation was monitored for marine mammals, add the following text: Vibratory monitoring results will include the maximum and overall average RMS calculated from 10-second RMS values during the drive of the pile for each of the functional hearing groups of Southall et al. (2007) (NMFS, 2012b).*
16. A description of any observable fish, marine mammal, or bird behavior in the immediate area will and, if possible, correlation to underwater sound levels occurring at that time.
17. *If airborne noise monitoring is required, broadband A-weighted and unweighted maximum, minimum, and average Lmax and Leq levels shall be tabulated for every pile. For each pile size and substrate type frequency spectra (one-third octave minimum frequency resolution) charts will be included to show the frequency content of Lmax and Leq signatures. The frequency content of airborne noise background levels shall also be shown. Background sound levels or L95 surrogate for background sound shall be reported.*

REFERENCES

Illingworth and Rodkin, Inc. 2001. Noise and Vibration Measurements Associated with the Pile Installation Demonstration Project for the San Francisco-Oakland Bay Bridge East Span, Final Data Report, Task Order 2, Contract No. 43A0063.

NMFS, 2012a. Guidance Document: Data Collection Methods to Characterize Underwater Background Sound Relevant to Marine Mammals in Coastal Nearshore Waters and Rivers of Washington and Oregon. Memorandum: NMFS Northwest Fisheries Science Center – Conservation Biology Division and Northwest Regional Office – Protected Resources Division, January 31, 2012.

NMFS, 2012b. Guidance Document: Data Collection Methods to Characterize Impact and Vibratory Pile Driving Source Levels Relevant to Marine Mammals. Memorandum: NMFS Northwest Fisheries Science Center – Conservation Biology Division and Northwest Regional Office – Protected Resources Division, January 31, 2012.

NMFS, 2012c. Guidance Document: Sound Propagation Modeling to Characterize Pile Driving Sounds Relevant to Marine Mammals. Memorandum: NMFS Northwest Fisheries Science Center – Conservation Biology Division and Northwest Regional Office – Protected Resources Division, January 31, 2012.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals 33(4): 411-521.

APPENDIX A

Calculation of Cumulative SEL

An estimation of individual SEL values can be calculated for each pile strike by calculating the following integral, where T is T_{90}, the period containing 90% of the cumulative energy of the pulse (eq. 1).

$$SEL = 10 \log\left(\int_0^T \frac{p^2(t)}{p_0^2} dt \right) \quad dB \qquad \text{(eq. 1)}$$

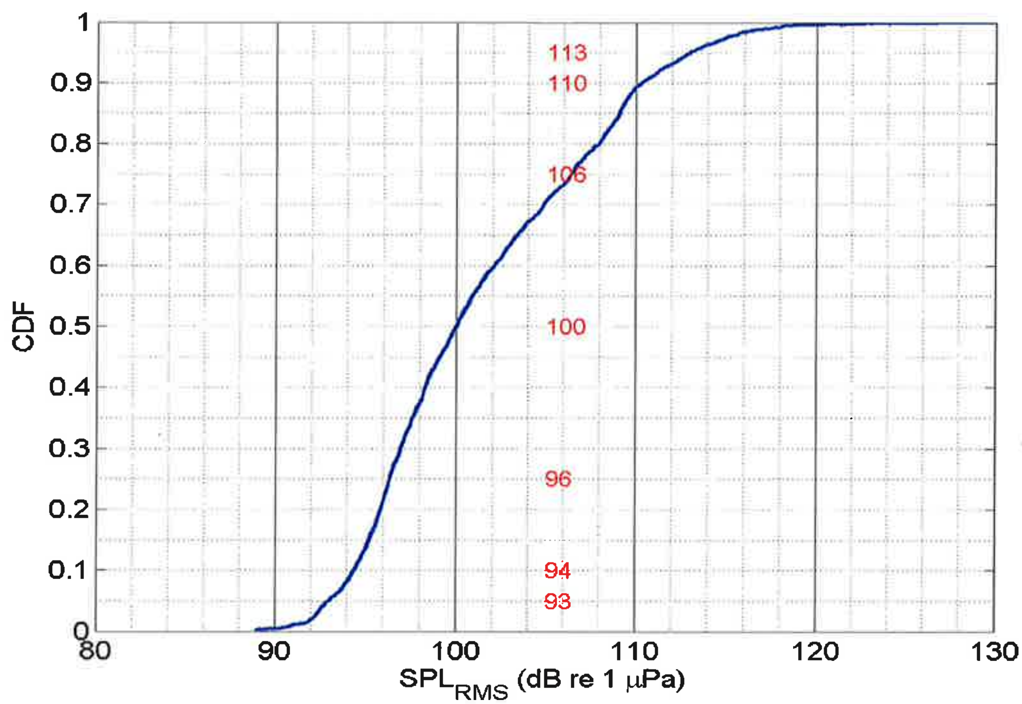
Calculating a cumulative SEL from individual SEL values cannot be accomplished simply by adding each SEL decibel level arithmetically. Because these values are logarithms they must first be converted to antilogs and then accumulated. Note, first, that if the single strike SEL is very close to a constant value (within 1 dB), then cumulative SEL = single strike SEL + 10 times log base 10 of the number of strikes N, i.e, $10Log_{10}(N)$. However if the single strike SEL varies over the sequence of strikes, then a linear sum of the energies for all the different strikes needs to be computed. This is done as follows: divide each SEL decibel level by 10 and then take the antilog. This will convert the decibels to linear units (or $uPa^2 \bullet s$). Next compute the sum of the linear units and convert this sum back into dB by taking $10Log_{10}$ of the value. This will be the cumulative SEL for all of the pile strikes.

APPENDIX B

Calculation of a Cumulative Distribution Function and Plot for Background Sound Level Analysis

Data from three full 24-hour underwater measurement cycles (minimum) are used to calculate a 30-second Root Mean Square (RMS) value for each 30-second period for the entire dataset. The RMS should be calculated for both the full frequency range recorded as well as a separate dataset which has been passed through a high pass filter thus eliminating those frequencies below 1000 Hz. These datasets are then grouped into 24-hour periods. To determine if the data is approximately log-normal in distribution, each 24-hour period is plotted as a Probability Density Function (PDF). Each 24-hour period can be plotted on the same PDF plot. The plots should be approximately log normal in distribution and thus can be used in the further analysis. Each day of data should have an approximately Gaussian sigmoid shape, the differences between them and the ideal might be hard to spot, but the sigmoid from day to day will show noticeable variation. Data which does not approximate a log normal distribution should be excluded from further analysis.

The Cumulative Distribution Function (CDF) plot is obtained by plotting the normalized cumulative sum vs. the bin location. You can also get the PDF from plotting the normalized bin count vs. the bin location. The normalized bin count is obtained by dividing the count column by (number of data points multiplied by the space between 2 consecutive bins). This provides the integral of the PDF equal to 1. For instructions on creating a histogram in Microsoft Excel, see: http://www.vertex42.com/ExcelArticles/mc/Histogram.html



1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
CDF
80
90
100
110
120
130
SPL$_{RMS}$ (dB re 1 μPa)
113
110
106
100
96
94
93

APPENDIX C

Table 1. Example table for required information for reporting the results of hydroacoustic monitoring of pile driving.

Date and Time	Pile ID	Hammer Impact or Vibratory	# Strikes or Vibratory Seconds	Distance to Pile from Hydrophone (m)	Water Depth (m)		Peak (dB)			$SEL_{90\%}$ (dB)				$RMS_{90\%}$ (dB)			Notes
					At Pile	At H-phone	Max	Min	Mean	Max	Min	Mean	$cSEL_{90\%}$	Max	Min	Mean	